

Finite Element Analysis Tutorial: Demonstrating processing flow

Three steps:

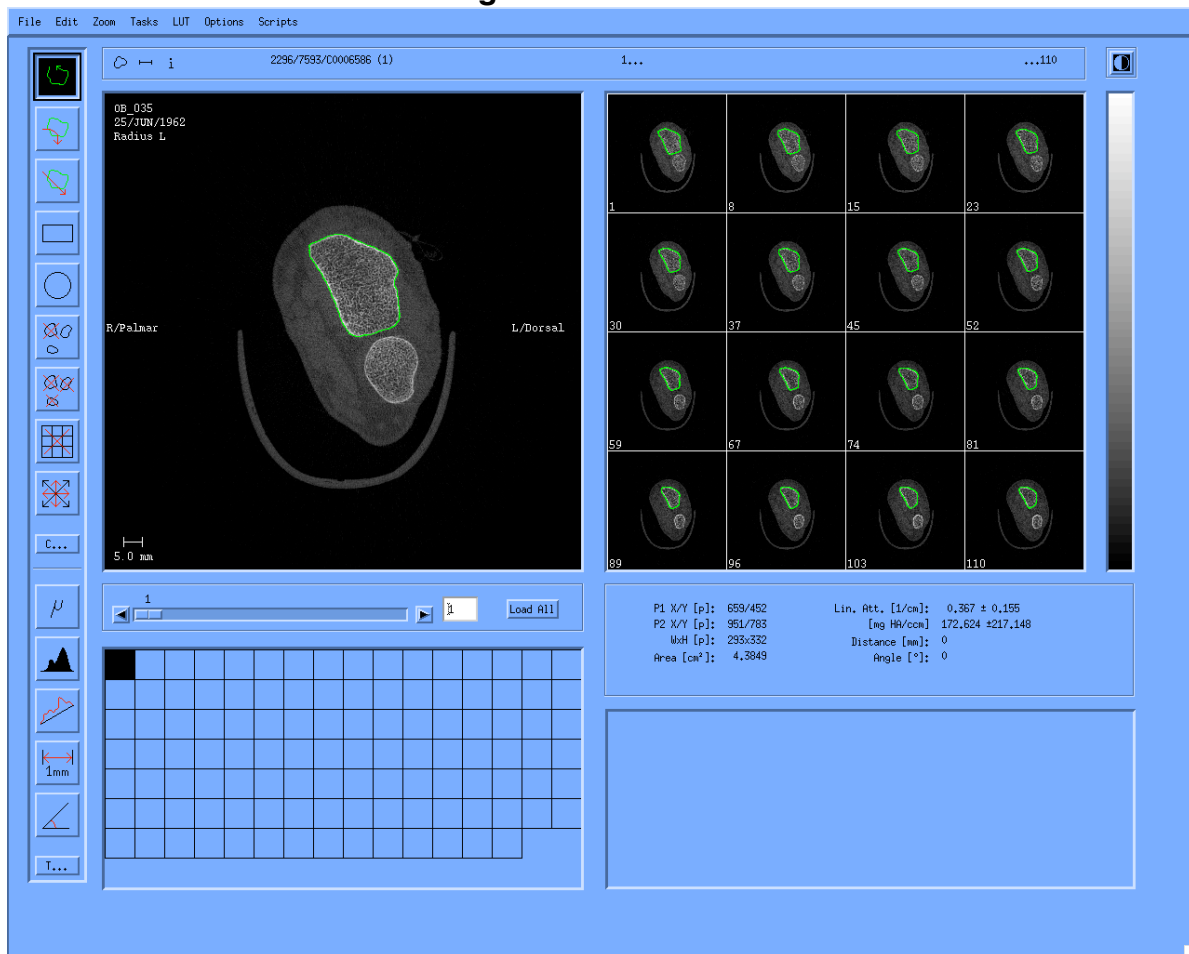
1. Pre-processing (generation of segmented file, meshing and boundary conditions).
2. Solver (running FAIM).
3. Post-processing (DAT and RES file, visualization with Paraview or UCT_3D).

File definitions:

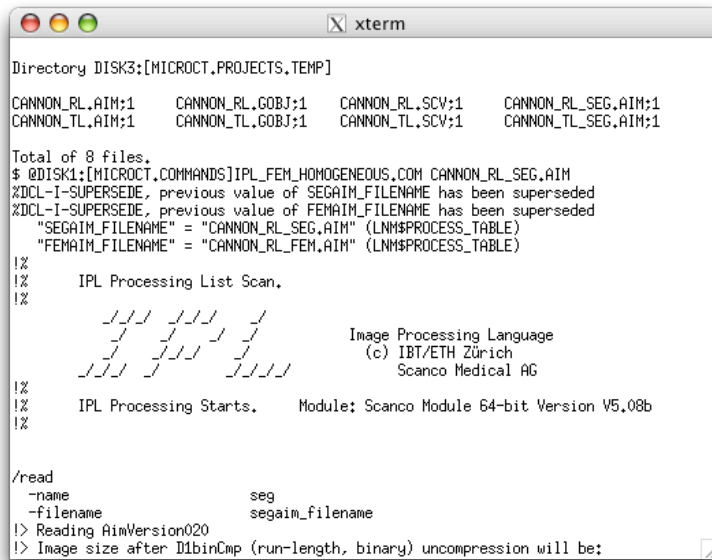
1. AIM - 3D image data (must be in range of 0-127 'char' for meshing).
2. INP - Input file for FE solver FAIM. Generated by AppDirectMechanicsGenerator (large file!).
3. LOG - Log file for FAIM.
4. DAT - Data output from FAIM (large file! Only necessary if results are to be visualized).
5. RES - Results summary.

Pre-processing

Generate the model for meshing



Convert the SEG file to the FEM file



```

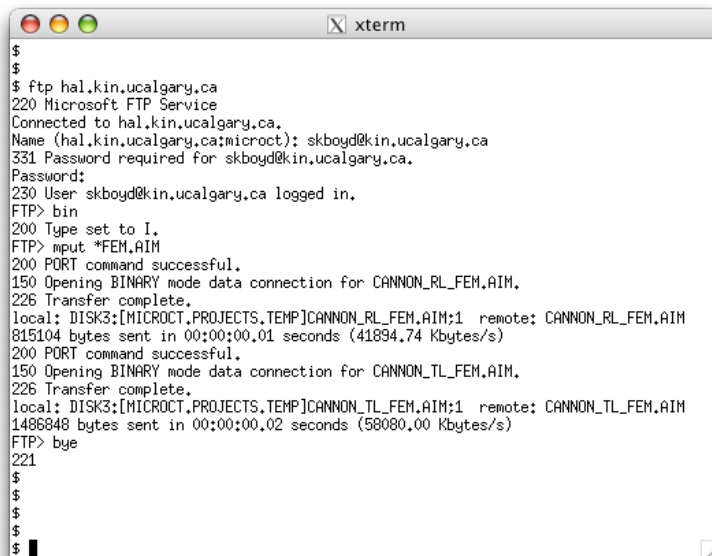
Directory DISK3:[MICROCT,PROJECTS,TEMP]

CANNON_RL.AIM:1    CANNON_RL.GOBJ:1    CANNON_RL.SCV:1    CANNON_RL_SEG.AIM:1
CANNON_TL.AIM:1    CANNON_TL.GOBJ:1    CANNON_TL.SCV:1    CANNON_TL_SEG.AIM:1

Total of 8 files.
$ @DISK1:[MICROCT,COMMANDS]IPL_FEM_HOMOGENEOUS.COM CANNON_RL_SEG.AIM
%DCL-I-SUPERSEDE, previous value of SEGAIM_FILENAME has been superseded
%DCL-I-SUPERSEDE, previous value of FEMAIM_FILENAME has been superseded
  "SEGAIM_FILENAME" = "CANNON_RL_SEG.AIM" (LNM$PROCESS_TABLE)
  "FEMAIM_FILENAME" = "CANNON_RL_FEM.AIM" (LNM$PROCESS_TABLE)
!%
!%      IPL Processing List Scan.
!%
!%      /\ /\ /\ /\ /\ /\
!%      /\ /\ /\ /\ /\ /\      Image Processing Language
!%      /\ /\ /\ /\ /\ /\      (c) IBT/ETH Zürich
!%      /\ /\ /\ /\ /\ /\      Scanco Medical AG
!%
!%      IPL Processing Starts.      Module: Scanco Module 64-bit Version V5.08b
!%

/read
-name                      seg
-filename                  segaim_filename
!> Reading AimVersion020
!> Image size after D1binCmp (run-length, binary) uncompression will be:
  
```

Transfer to mighty-mac



```

$
$
$ ftp hal.kin.ucalgary.ca
220 Microsoft FTP Service
Connected to hal.kin.ucalgary.ca.
Name (hal.kin.ucalgary.ca:microct): skboyd@kin.ucalgary.ca
331 Password required for skboyd@kin.ucalgary.ca.
Password:
230 User skboyd@kin.ucalgary.ca logged in.
FTP> bin
200 Type set to I.
FTP> mput *FEM.AIM
200 PORT command successful.
150 Opening BINARY mode data connection for CANNON_RL_FEM.AIM.
226 Transfer complete.
local: DISK3:[MICROCT,PROJECTS,TEMP]CANNON_RL_FEM.AIM:1 remote: CANNON_RL_FEM.AIM
815104 bytes sent in 00:00:00.01 seconds (41894.74 Kbytes/s)
200 PORT command successful.
150 Opening BINARY mode data connection for CANNON_TL_FEM.AIM.
226 Transfer complete.
local: DISK3:[MICROCT,PROJECTS,TEMP]CANNON_TL_FEM.AIM:1 remote: CANNON_TL_FEM.AIM
1486848 bytes sent in 00:00:00.02 seconds (58080.00 Kbytes/s)
FTP> bye
221
$
$
$
$
$
  
```

```

xterm
bash-3.2$ ssh -Y mighty-mac.kin.ucalgary.ca
Password:
Last login: Wed Oct  7 12:27:28 2009 from 136.159.130.63
mighty-mac:~$ skboyd$ cd /Volumes/data1/
mighty-mac:data1 skboyd$ ls
ammann      grace_sca    helen        kyle
mighty-mac:data1 skboyd$ mkdir cannon
mighty-mac:data1 skboyd$ cd cannon
mighty-mac:cannon skboyd$ ftp hal.kin.ucalgary.ca
Trying 136.159.130.20...
Connected to hal.kin.ucalgary.ca.
220 Microsoft FTP Service
Name (hal.kin.ucalgary.ca:skboyd): skboyd@kin.ucalgary.ca
331 Password required for skboyd@kin.ucalgary.ca.
Password:
230 User skboyd@kin.ucalgary.ca logged in.
Remote system type is Windows_NT.
ftp> bin
200 Type set to I.
ftp> prompt off
Interactive mode off.
ftp> mget *FEM,AIM
'EPSV': command not understood
local: CANNON_RL_FEM,AIM remote: CANNON_RL_FEM,AIM
227 Entering Passive Mode (136,159,130,20,14,150).
125 Data connection already open; Transfer starting.
100% |*****| 796 KB 4.08 MB/s 00:00 ETA
226 Transfer complete.
815104 bytes received in 00:00 (4.08 MB/s)
local: CANNON_TL_FEM,AIM remote: CANNON_TL_FEM,AIM
227 Entering Passive Mode (136,159,130,20,14,151).
125 Data connection already open; Transfer starting.
100% |*****| 1452 KB 5.57 MB/s 00:00 ETA
226 Transfer complete.
1486848 bytes received in 00:00 (5.57 MB/s)
ftp>

```

Mesh and Solve

Prepare scripts

```

xterm
mighty-mac:cannon skboyd$ ls
CANNON_RL_FEM,AIM  mesh_solve_clean.com
CANNON_TL_FEM,AIM  submit_cannon.com
mighty-mac:cannon skboyd$ vi mesh_solve_clean.com

```

mesh_solve_clean.com

```

xterm
# Generate the mesh
echo "Generating $1.inp"
AppDirectMechanicsGenerator -v 4.0 -d 2 -e 1.7 -i 1 1 -s -0.01 -k 0 $1.AIM

# Solve the FE model
echo "Solving FE model"
faim_d -solver mt -threads 8 $1_z

# Delete the mesh
echo "Removing $1_z.inp"
rm $1_z.inp
#echo "Removing $1_z.log"
#rm $1_z.log
echo "Compressing $1_z.dat"
bzip2 $1_z.dat
#echo "Removing $1_z.dat"
#rm $1_z.dat
echo " "
echo "=====
exit
"
"mesh_solve_clean.com" 20L, 469C

```

AppDirectMechanicsGenerator

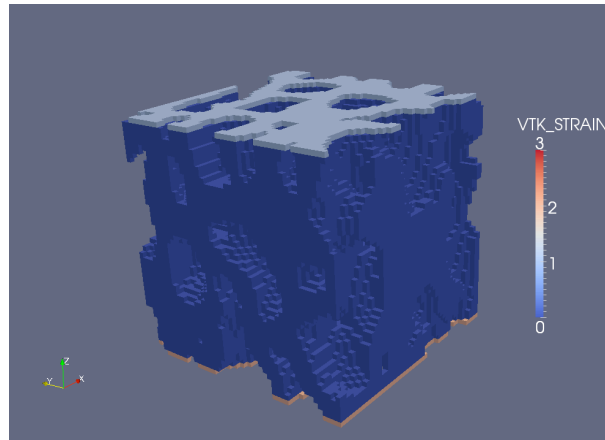
```

xterm
mighty-mac:cannon skboyd$ AppDirectMechanicsGenerator
AppDirectMechanicsGenerator
db 14-JUL-2008
sb 23-JUL-2009
sb 24-SEP-2009
Usage: AppDirectMechanicsGenerator [-a] infile.aim (outfile)
-o # : set output file format (df, FAIM)
      0=MARC
      1=FAIM
-v # : FAIM input file version 1.5, 2.0, 3.0 or 4.0 (df, 4.0)
-d # : set test, or 6 for confined strain dir mech (df, Z=2)
      0=X
      1=Y
      2=Z
      3=XS
      4=YS
      5=ZS
      6=ALL
-u # : upper BCs on an uneven surface (df, off)
-f # : Apply BCs to a specific material id only (df, all)
-p # : Generate an element set for the plane midway along testing axis (i.e., for endcaps)
-b # : Overrides df BCs
      0=UNIAXIAL          axial test
      1=AXIAL            axial test
      2=CONFINED AXIAL   axial test
      3=SHEAR PLANE STRESS shear test
      4=SHEAR PLANE STRAIN shear test
      5=SHEAR SUBSTITUTE MODEL shear test
-r # : set test to torsion
      # is degrees of rotation
      positive rotation is ccw
      set -s for torsion with pre-compression
-a # # # : set centroid position (df, 0 0 0)
      first #: 0 = centre of mass calculation
      1 = set centroid to (0,0)
      second #: move centroid in offAxis1 direction (df, x) units are mm
      third #: move centroid in offAxis2 direction (df, y) units are mm
-k # : set density to material model (df, 0)
      0=Exponential, failed elements scaled
      1=Exponential, failed elements fixed
      2=Constant E for load sharing, failed elements fixed
      3=Constant E for 127 to 100, endcaps for 99 to 1, failed elements fixed
-t # : set max tension
-c # : set max compression
-e # : set exponent for density relationship
-s # : set engineering strain (df, -0.01 -> compressive)
-m # : set isotropic modulus
-i # # : set plastic iterations and exit iterations (df, 1 1)

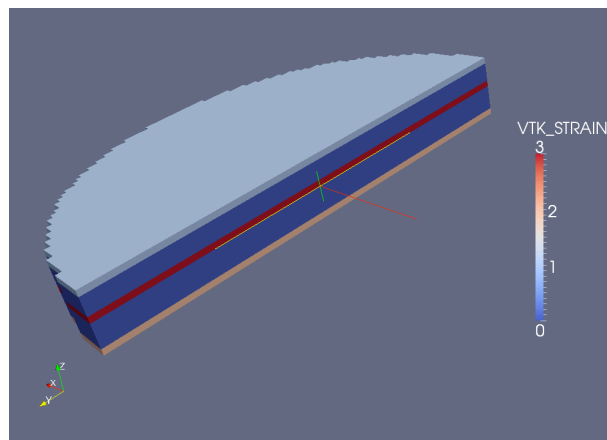
Example: AppDirectMechanicsGenerator -d 2 -e 1.7 -i 1 1 -s -0.01 -m 6829 test25a.aim
mighty-mac:cannon skboyd$

```

- Boundary conditions at min/max Z. These are also the sites used for determining load sharing.



- There is an option to include a middle layer of elements using AppDirectMechanicsGenerator ('-p' option)

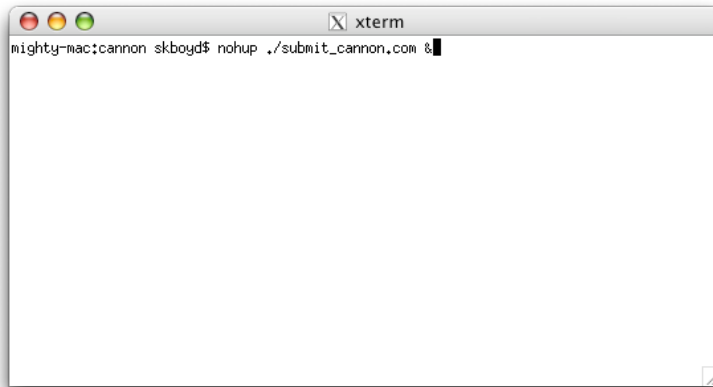


A look at the script for submitting multiple jobs (submit_cannon.com)

[illegible]

Submit the jobs

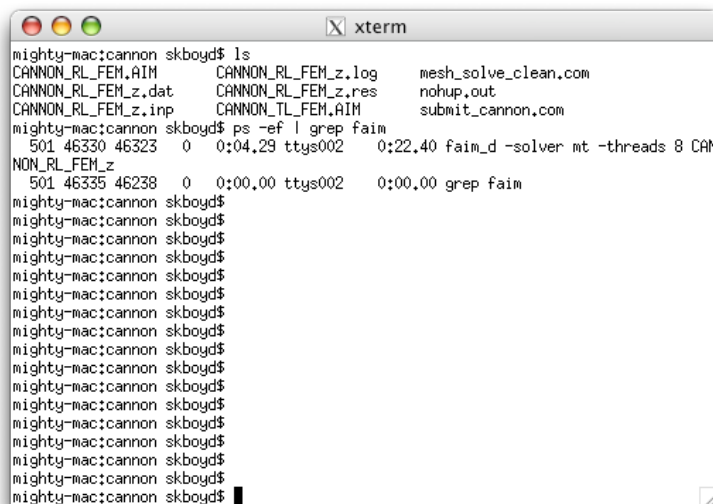
- Sets a process that will continue after logging out.



```
mighty-mac:cannon skboyd$ nohup ./submit_cannon.com &
```

Check the models are running

- Take a look at the nohup.out file, and any *.log files.



```
mighty-mac:cannon skboyd$ ls
CANNON_RL_FEM.AIM      CANNON_RL_FEM_z.log      mesh_solve_clean.com
CANNON_RL_FEM_z.dat    CANNON_RL_FEM_z.res      nohup.out
CANNON_RL_FEM_z.inp    CANNON_TL_FEM.AIM        submit_cannon.com

mighty-mac:cannon skboyd$ ps -ef | grep fail
501 46330 46323  0  0:04.29 ttys002    0:22.40 fail_d -solver mt -threads 8 CAN
NON_RL_FEM_z
501 46335 46238  0  0:00.00 ttys002    0:00.00 grep fail

mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
```

Monitor LOG file to watch job progression

```

=====
Time stamp:      15/10/2009      15:37:45
=====
INPUT  CANNON_RL_FEM_z.inp
BUILD ELEMENT STIFFNESS MATRIX
WRITE NODES AND ELEMENTS CANNON_RL_FEM_z.dat

STEP      1
=====
BUILD PRECONDITIONER
START SOLVER
#      1  0.0000E+00
#      2  0.1000E+01
#      3  0.8820E+00
#      4  0.7496E+00
#      5  0.8267E+00
#     10  0.7747E+00
#     15  0.5909E+00
#     20  0.2858E+00
#     25  0.2081E+00
#     50  0.1664E+00
#    100  0.8098E-01
#    150  0.3739E-01
#    200  0.3809E-01
#    250  0.1930E-01
#     500 0.6206E-02
#    1000 0.2169E-02
~
~
~
(END)

```

Converged!

```

#    100 0.8098E-01
#    150 0.3739E-01
#    200 0.3809E-01
#    250 0.1930E-01
#     500 0.6206E-02
#    1000 0.2169E-02
#    2000 0.2589E-03
#   2302 0.9995E-04
CONVERGED

=====
Table 4: Conjugate Gradient Load Step
=====
Current step:      1
Number of steps:  1
Load step at exit: 1
Failed voxels:    0
Convergence criteria: 0.1000E-03
Convergence measure: 0.9995E-04
Iterations to convergence: 2302
=====
POST PROCESSING
OUTPUT CANNON_RL_FEM_z.dat
SUMMARIZING RESULTS

=====
MODEL SOLVED

=====
Time stamp:      15/10/2009      15:53:44
=====

```

Generated Files

- CANNON_RL_FEM_z.dat.bz2
- CANNON_RL_FEM_z.res
- CANNON_RL_FEM_z.log
- Note that the INP file was deleted as per mesh_solve_clean.com

Results File

```
=====
Time stamp:      15/10/2009      15:37:45
=====
```

Table 1: Model Input

```
-----
FAIM version:      4.03
Filename:          CANNON_RL_FEM_z
Element:           hexahedron
Element dim X:     0.0820
Element dim Y:     0.0820
Element dim Z:     0.0820
Number of nodes:   3065396
Number of elements: 1944705
Number of integration points: 8
Number of freedoms per node: 3
Number of nodes per element: 8
Dimension of problem: 3
Tolerance:         0.1000E-03
Maximum number of iterations: 30000
Number of equations: 9165851
Number of steps:   1
Number of steps at exit: 1
Maximum compression: -0.4930E-01
Maximum tension:    0.2950E-01
Total load:         0.0000E+00
=====
```

Table 2: Model Material Table

```
-----
Number of materials available: 254
Number of materials used:     1
Isotropic material:           true
-----
   id      E      v      G
127 0.6829E+04 0.3000E+00 0.2627E+04
=====
```

Table 3: Model Material Distribution

```
-----
   material  # voxels  %
   127      1944705  100.0000
-----
   total    1944705  100.0000
=====
```

Table 4: Conjugate Gradient Load Step

```
-----
Current step:      1
Number of steps:   1
Load step at exit: 1
Failed voxels:     0
Convergence criteria: 0.1000E-03
Convergence measure: 0.9995E-04
Iterations to convergence: 2302
=====
```

Table 5: Tissue Stresses

```
-----
Material:          ALL
Number of elements: 1944705
-----
.....
          s11      s22      s33      s12      s23      s31      sVM
average 0.7097E-02 -0.1439E-01 -0.3244E+02 -0.1086E-01 -0.3590E-03 0.2832E-02 0.3973E+02
std_dev 0.8824E+01 0.7983E+01 0.2521E+02 0.4832E+01 0.7166E+01 0.7750E+01 0.2238E+02
minimum -0.1452E+03 -0.1083E+03 -0.3640E+03 -0.1193E+03 -0.1753E+03 -0.9009E+02 0.0000E+00
maximum 0.1928E+03 0.2202E+03 0.8349E+02 0.8076E+02 0.1184E+03 0.1213E+03 0.3619E+03
skewness 0.8618E+00 0.5127E+00 -0.7350E+00 -0.4299E+00 -0.2936E+00 0.2424E+00 0.6962E+00
kurtosis 0.1068E+02 0.9843E+01 0.1305E+01 0.6398E+01 0.5307E+01 0.3361E+01 0.1525E+01
median -0.2648E+00 -0.7436E-01 -0.3021E+02 0.9105E-01 -0.6480E-02 0.3118E-01 0.3838E+02
percentile05 -0.1239E+02 -0.1195E+02 -0.7433E+02 -0.7919E+01 -0.1157E+02 -0.1213E+02 0.6639E+01
percentile25 -0.3645E+01 -0.3517E+01 -0.5035E+02 -0.2158E+01 -0.3303E+01 -0.4393E+01 0.2290E+02
=====
```

```

percentile75 0.2818E+01 0.3189E+01 -0.1181E+02 0.2409E+01 0.3593E+01 0.4075E+01 0.5420E+02
percentile95 0.1435E+02 0.1229E+02 0.8266E+00 0.7132E+01 0.1126E+02 0.1250E+02 0.7737E+02
fraction_below_zero 0.5332E+00 0.5120E+00 0.9270E+00 0.4828E+00 0.5022E+00 0.4937E+00 0.0000E+00
ave_neg -0.5174E+01 -0.5115E+01 -0.3525E+02 -0.3457E+01 -0.4966E+01 -0.5696E+01 0.0000E+00
med_neg -0.3336E+01 -0.3400E+01 -0.3289E+02 -0.2274E+01 -0.3282E+01 -0.4474E+01 0.0000E+00
ave_pos 0.5926E+01 0.5337E+01 0.3157E+01 0.3206E+01 0.5009E+01 0.5561E+01 0.3973E+02
med_pos 0.3177E+01 0.3314E+01 0.1780E+01 0.2300E+01 0.3616E+01 0.4004E+01 0.3838E+02
=====

```

Table 6: Tissue Strains

```

=====
Material: ALL
Number of elements: 1944705
.....
          e11      e22      e33      e12      e23      e31      SED
average 0.1427E-02 0.1423E-02 -0.4751E-02 -0.4133E-05 -0.1367E-06 0.1078E-05 0.1528E+00
std_dev 0.1465E-02 0.1331E-02 0.3517E-02 0.1840E-02 0.2728E-02 0.2951E-02 0.1750E+00
minimum -0.1825E-01 -0.1166E-01 -0.4850E-01 -0.4544E-01 -0.6676E-01 -0.3430E-01 0.0000E+00
maximum 0.2592E-01 0.2987E-01 0.9547E-02 0.3075E-01 0.4507E-01 0.4619E-01 0.1050E+02
skewness 0.4658E+00 0.3198E+00 -0.6857E+00 -0.4299E+00 -0.2936E+00 0.2424E+00 0.4705E+01
kurtosis 0.3001E+01 0.2328E+01 0.9709E+00 0.6398E+01 0.5307E+01 0.3361E+01 0.6987E+02
median 0.1327E-02 0.1413E-02 -0.4430E-02 0.3467E-04 -0.2467E-05 0.1187E-04 0.1067E+00
percentile05 -0.5783E-03 -0.5181E-03 -0.1067E-01 -0.3015E-02 -0.4407E-02 -0.4617E-02 0.3096E-02
percentile25 0.4003E-03 0.4804E-03 -0.7238E-02 -0.8217E-03 -0.1257E-02 -0.1673E-02 0.3718E-01
percentile75 0.2331E-02 0.2252E-02 -0.1898E-02 0.9170E-03 0.1368E-02 0.1551E-02 0.2156E+00
percentile95 0.3849E-02 0.3598E-02 0.1466E-04 0.2715E-02 0.4288E-02 0.4758E-02 0.4421E+00
fraction_below_zero 0.1420E+00 0.1315E+00 0.9444E+00 0.4828E+00 0.5022E+00 0.4937E+00 0.0000E+00
ave_neg -0.6265E-03 -0.5798E-03 -0.5055E-02 -0.1316E-02 -0.1891E-02 -0.2169E-02 0.0000E+00
med_neg -0.3617E-03 -0.3547E-03 -0.4708E-02 -0.8659E-03 -0.1250E-02 -0.1704E-02 0.0000E+00
ave_pos 0.1767E-02 0.1726E-02 0.4222E-03 0.1221E-02 0.1907E-02 0.2117E-02 0.1528E+00
med_pos 0.1599E-02 0.1618E-02 0.2457E-03 0.8758E-03 0.1377E-02 0.1525E-02 0.1067E+00
=====

```

Table 7: Nodal Displacements

```

=====
Number of node sets: 2
-----
Node set: 1
Number of nodes: 22892
+-----
          Ux      Uy      Uz
average 0.1419E-01 -0.1106E-01 -0.8528E-01
std_dev 0.8994E-02 0.8577E-02 0.1303E-06
minimum -0.1170E-01 -0.4110E-01 -0.8528E-01
maximum 0.5608E-01 0.2675E-01 -0.8528E-01
median 0.1458E-01 -0.1070E-01 -0.8528E-01
-----
Node set: 2
Number of nodes: 30337
+-----
          Ux      Uy      Uz
average -0.1493E-01 0.1054E-01 0.0000E+00
std_dev 0.3115E-01 0.3033E-01 0.0000E+00
minimum -0.7915E-01 -0.7555E-01 0.0000E+00
maximum 0.5922E-01 0.7340E-01 0.0000E+00
median -0.1625E-01 0.1049E-01 0.0000E+00
=====

```

Table 8: Nodal Forces

```

=====
Number of node sets: 2
-----
Node set: 1
Number of nodes: 22892
+-----
          Fx      Fy      Fz
total 0.1046E-02 -0.1985E-02 -0.4079E+04
average 0.4571E-07 -0.8672E-07 -0.1782E+00
std_dev 0.4075E-04 0.4157E-04 0.1922E+00
minimum -0.3426E-03 -0.4049E-03 -0.1210E+01
maximum 0.3695E-03 0.4074E-03 0.1143E+00
median 0.4139E-07 0.7536E-07 -0.1125E+00
-----
Node set: 2
Number of nodes: 30337
+-----
          Fx      Fy      Fz
total -0.7377E-02 0.1019E-01 0.4079E+04

```

```

average -0.2432E-06  0.3360E-06  0.1345E+00
std_dev  0.9434E-05  0.9251E-05  0.1595E+00
minimum -0.1019E-03 -0.6381E-04 -0.2891E+00
maximum  0.5274E-04  0.6749E-04  0.1264E+01
median   -0.1211E-06  0.1265E-06  0.8649E-01

```

=====

Table 9: Load Sharing (by elements)

```

-----
Number of element sets:                2
Element area x-y face:                0.6724E-02
Element area y-z face:                0.6724E-02
Element area z-x face:                0.6724E-02
-----
Element set:                          1
Number of elements:                   17182
+-----
      material      Fx      Fy      Fz      % Fz
      -----
      127 -0.8340E+03 -0.7196E+03 -0.4079E+04  100.00
      -----
      total -0.8340E+03 -0.7196E+03 -0.4079E+04  100.00
-----
Element set:                          2
Number of elements:                   20342
+-----
      material      Fx      Fy      Fz      % Fz
      -----
      127  0.3093E+03  0.2605E+03 -0.4079E+04  100.00
      -----
      total  0.3093E+03  0.2605E+03 -0.4079E+04  100.00
-----

```

NOTE: Total Fx & Fy are determined by summing over the element faces. Therefore, total Fx & Fy are different than reported in Nodal Forces (Table 8). Total Fz should be identical.

=====

Table 10: Failure Load Estimate

Pistoia Criterion for Energy-Equivalent-Strain (EES)
 (*) Results valid for linear, isotropic model only.

```

-----
Number of elements in analysis:        1944705
Excluded material id:                 none
-----
Critical volume (%):                  2.0000
Critical EES:                         0.0070
EES at vol_crit:                      0.0134
Factor (from table):                  0.5226E+00
Reaction force Z:                     -0.4079E+04
Failure load (rfz / factor) [N]:      -0.2132E+04
Stiffness [N/mm]:                     0.4783E+05
-----

```

Distribution of energy-equivalent-strain: EES = sqrt(2U/E).

```

-----
      EES
      average 0.5806E-02
      std_dev 0.3325E-02
      minimum 0.0000E+00
      maximum 0.5546E-01
      skewness 0.7718E+00
      kurtosis 0.1902E+01
      median 0.5589E-02
-----

```

Distribution of failed materials.

```

-----
      material      # els      %
      -----
      127          38895    100.0000
      -----
      total          38895    100.0000
-----

```

Factor table:

	crit_vol	crit_ees				
%	# vox	0.0050	0.0060	0.0070	0.0080	0.0090
1.00	1944705	0.3325E+00	0.3990E+00	0.4655E+00	0.5320E+00	0.5986E+00
2.00	3889410	0.3733E+00	0.4480E+00	0.5226E+00	0.5973E+00	0.6720E+00
3.00	5834115	0.4002E+00	0.4802E+00	0.5602E+00	0.6402E+00	0.7203E+00
4.00	7778820	0.4218E+00	0.5062E+00	0.5906E+00	0.6749E+00	0.7593E+00
5.00	9723525	0.4394E+00	0.5273E+00	0.6152E+00	0.7030E+00	0.7909E+00

```

6.00 11668230 | 0.4547E+00 0.5456E+00 0.6365E+00 0.7274E+00 0.8184E+00
7.00 13612935 | 0.4682E+00 0.5618E+00 0.6554E+00 0.7491E+00 0.8427E+00
=====

```

Table 20: Computational Cost

Number of threads:	8			
Device number:	0			
Solver:	multi-threaded			
Precision:	double			
Computation time	wall (s)		cpu (s)	
	time	delta	time	delta
Read input	21.2140	21.2140	21.2098	21.2098
Pre-processing	48.8500	27.6360	48.0787	26.8689
Solver	870.1450	821.2950	5666.1918	5618.1131
Write DAT file	943.9990	73.8540	5738.4095	72.2176
Element summary	957.1570	13.1580	5751.5666	13.1571
Nodal summary	958.0020	0.8450	5752.4120	0.8454
Load sharing	958.0090	0.0070	5752.4184	0.0064
Failure estimate	959.4580	1.4490	5753.8678	1.4495
% solver	90.7	%	98.5	%
% pre/post	9.3	%	1.5	%
Charged time	959.4580	s	5753.8678	s

Table 19: One Liner

```

yy
num_eqns      max_comp      filename      faim_version      num_els      num_nodes      tolerance
num_mat_id2   mat_id3      max_tens      num_materials      mat_id1      num_mat_id1      mat_id2
es2_fz_total  es2_fz_mat1  es2_fz_mat2  es2_fz_mat3      es1_fz_mat1  es1_fz_mat2      es1_fz_mat3
es3_fz_mat3   fz_total     failure_load  stiffness         es3_fz_total  es3_fz_mat1      es3_fz_mat2
xy CANNON_RL_FEM_z      4.03      wtime_solver  wtime_prepost  wtime_total
9165851      -0.4930E-01  0.2950E-01      1      127      1944705      3065396      0.1000E-03
0      0      0      -0.4079E+04      -0.4079E+04      0.0000E+00      0.0000E+00      -0.4079E
+04      -0.4079E+04      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00      0.0000E+00
0.0000E+00      -0.4079E+04      -0.2132E+04      0.4783E+05      821.29      138.16      959.46
=====

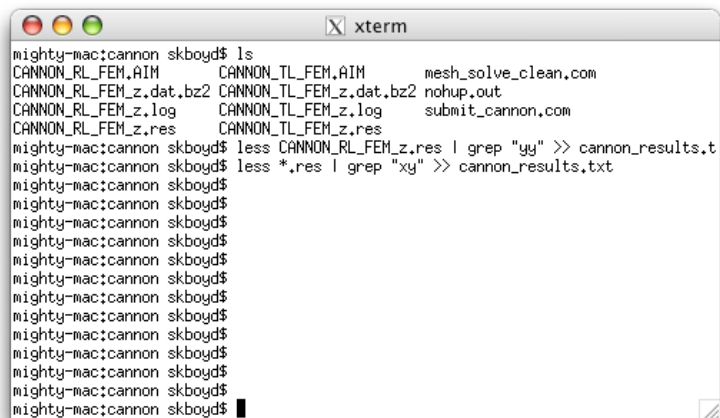
```

```

Time stamp:      15/10/2009      15:53:44
=====

```

Extract summary results



```

mighty-mac:cannon skboyd$ ls
CANNON_RL_FEM.AIM      CANNON_TL_FEM.AIM      mesh_solve_clean.com
CANNON_RL_FEM_z.dat.bz2 CANNON_TL_FEM_z.dat.bz2 nohup.out
CANNON_RL_FEM_z.log     CANNON_TL_FEM_z.log     submit_cannon.com
CANNON_RL_FEM_z.res     CANNON_TL_FEM_z.res
mighty-mac:cannon skboyd$ less CANNON_RL_FEM_z.res | grep "yy" >> cannon_results.t
mighty-mac:cannon skboyd$ less *.res | grep "xy" >> cannon_results.txt
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$
mighty-mac:cannon skboyd$

```

Import into Excel

- Note that not all the information in the RES file is included.

	A	B	C	D	E	F	G	H	I	J	K	L	
	file name	faim_version	num_el	num_nodes	tolerance	num_eqns	max_comp	max_tens	num_material	mat_id1	mat_id2	num	
2	CANNON_RL_FEM_z	4.03	1944705	3065396	1.00E-04	9165851	-4.91E-02	2.95E-02	1	177	1944705	0	
3	CANNON_TL_FEM_z	4.03	4403842	6422722	1.00E-04	19203555	-4.93E-02	2.95E-02	1	127	4403842	0	
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													

Post-Processing

Convert to DAT to VTK format for use with Paraview

```

bash-3.2$ AppFaim2Vtk
Usage: AppFaim2Vtk [-args] file.dat (output.vtk)
  -disp      : read nodal displacements (df, off)
  -force     : read nodal forces (df, off)
  -elstrain  : read element strains (df, off)
  -stress    : read element stresses (df, on)
  -ascii     : write ascii file (df, binary)

Default is to read element stresses.

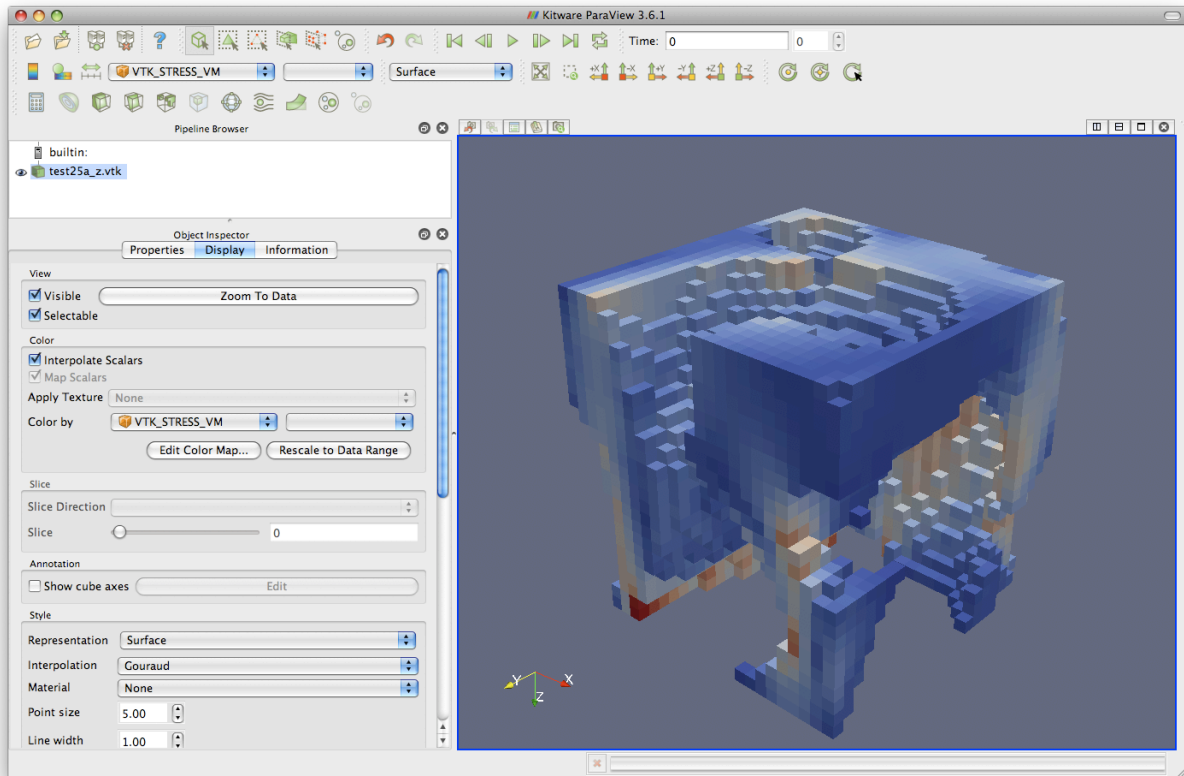
bash-3.2$ AppFaim2Vtk -disp -elstrain -force -stress CANNON_RL_FEM_z.dat

Input File -----
      CANNON_RL_FEM_z.dat

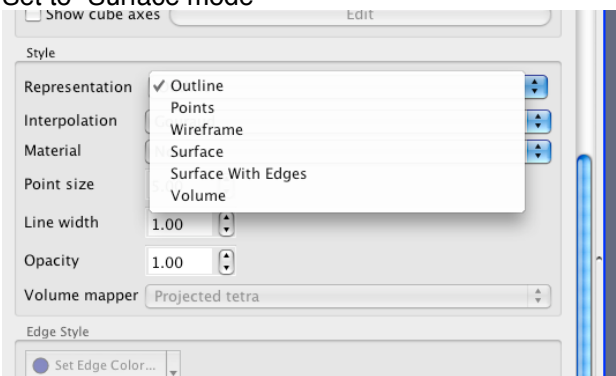
DAT File -----
POINT DATA:
Array 0 (nodaldisplacements): 3065396 tup, 3 comp, [-0.08119, 0.05922]
Array 1 (nodalreactionforces): 3065396 tup, 3 comp, [-0.00292, 0.002941]
CELL DATA:
Array 0 (VTK_STRESS_VM): 1944705 tup, 1 comp, [0.361,9]
Array 1 (VTK_STRESS_11): 1944705 tup, 1 comp, [-145.2, 192.8]
Array 2 (VTK_STRESS_22): 1944705 tup, 1 comp, [-108.3, 220.2]
Array 3 (VTK_STRESS_33): 1944705 tup, 1 comp, [-364.83,49]
Array 4 (VTK_STRESS_12): 1944705 tup, 1 comp, [-119.3, 80.76]
Array 5 (VTK_STRESS_23): 1944705 tup, 1 comp, [-175.3, 118.4]
Array 6 (VTK_STRESS_31): 1944705 tup, 1 comp, [-90.09, 121.3]
Array 7 (VTK_STRAIN_11): 1944705 tup, 1 comp, [-0.01825, 0.02592]
Array 8 (VTK_STRAIN_22): 1944705 tup, 1 comp, [-0.01166, 0.02987]
Array 9 (VTK_STRAIN_33): 1944705 tup, 1 comp, [-0.0485, 0.009547]
Array 10 (VTK_STRAIN_12): 1944705 tup, 1 comp, [-0.04544, 0.03075]
Array 11 (VTK_STRAIN_23): 1944705 tup, 1 comp, [-0.06576, 0.04507]
Array 12 (VTK_STRAIN_31): 1944705 tup, 1 comp, [-0.0343, 0.04619]
Array 13 (VTK_STRAIN_SE): 1944705 tup, 1 comp, [0, 10.5]
Array 14 (FAILED): 1944705 tup, 1 comp, [0, 0]

Output File -----
      CANNON_RL_FEM_z.vtk
bash-3.2$

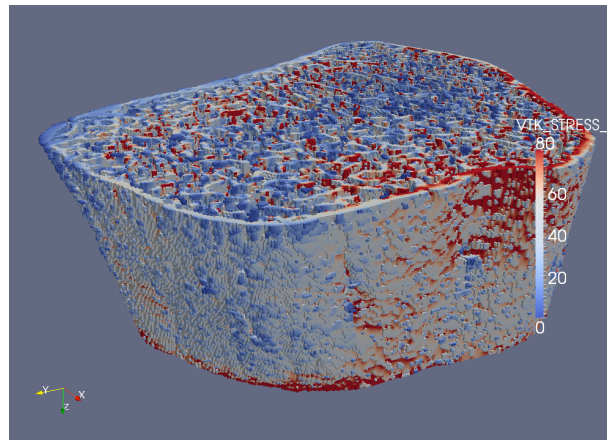
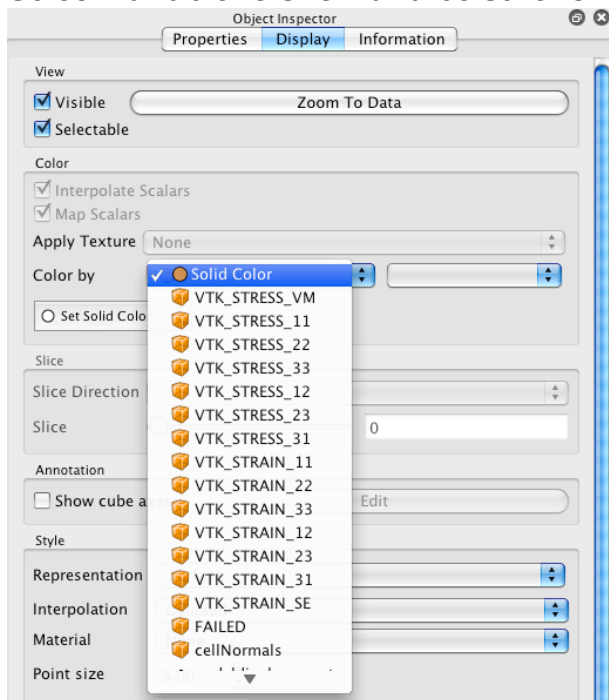
```

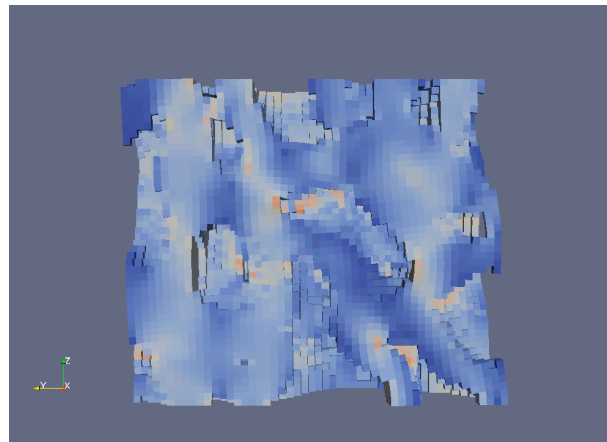
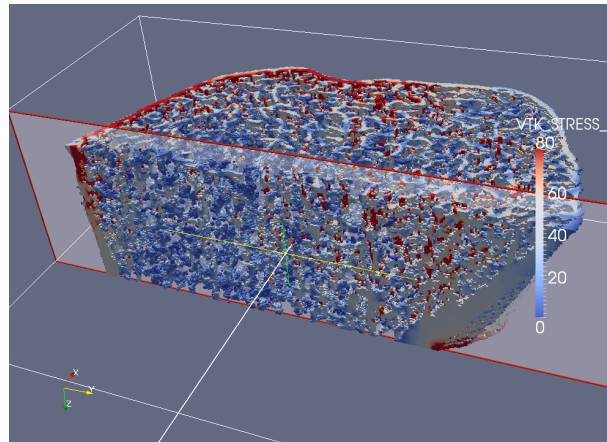


Set to "Surface mode"



Select variable to show and be sure to re-scale the data range if necessary.





Use AppFaim2Aim

```

bash-3.2$ AppFaim2Aim
Usage: AppFaim2Aim [-args] file.dat file.aim
Program requires both the DAT and the original AIM file.
It writes an output AIM based on the structure of the input
AIM, but with the data from the DAT file.
  -a arg1 = : attribute data (df, 6)
    0 - VTK_STRESS_11
    1 - VTK_STRESS_22
    2 - VTK_STRESS_33
    3 - VTK_STRESS_12
    4 - VTK_STRESS_23
    5 - VTK_STRESS_31
    6 - VTK_STRESS_VM
    7 - VTK_STRAIN_11
    8 - VTK_STRAIN_22
    9 - VTK_STRAIN_33
   10 - VTK_STRAIN_12
   11 - VTK_STRAIN_23
   12 - VTK_STRAIN_31
   13 - VTK_STRAIN_SE
   14 - FAILED
  -w arg1 : window size (df, 600x600 pixels)
  -x      : suppress visualization (df, off)

bash-3.2$ AppFaim2Aim -a 6 CANNON_RL_FEM_z.dat CANNON_RL_FEM.AIM
-----
Filenames
  Input DAT: CANNON_RL_FEM_z.dat
  Input AIM: CANNON_RL_FEM.AIM
  Output AIM: CANNON_RL_FEM_z_svm.aim
-----
DAT File
POINT DATA:
none
CELL DATA:
Array 0 (VTK_STRESS_11): 1944705 tup, 1 comp, [-145.2, 192.8]
Array 1 (VTK_STRESS_22): 1944705 tup, 1 comp, [-108.3, 220.2]
Array 2 (VTK_STRESS_33): 1944705 tup, 1 comp, [-364, 83.49]
Array 3 (VTK_STRESS_12): 1944705 tup, 1 comp, [-119.3, 80.76]
Array 4 (VTK_STRESS_23): 1944705 tup, 1 comp, [-175.3, 118.4]
Array 5 (VTK_STRESS_31): 1944705 tup, 1 comp, [-90.09, 121.3]
Array 6 (VTK_STRESS_VM): 1944705 tup, 1 comp, [0, 361.9]
Array 7 (VTK_STRAIN_11): 1944705 tup, 1 comp, [-0.01825, 0.02592]
Array 8 (VTK_STRAIN_22): 1944705 tup, 1 comp, [-0.01166, 0.02987]
Array 9 (VTK_STRAIN_33): 1944705 tup, 1 comp, [-0.0485, 0.009547]
Array 10 (VTK_STRAIN_12): 1944705 tup, 1 comp, [-0.04544, 0.03075]
Array 11 (VTK_STRAIN_23): 1944705 tup, 1 comp, [-0.06676, 0.04507]
Array 12 (VTK_STRAIN_31): 1944705 tup, 1 comp, [-0.0343, 0.04619]
Array 13 (VTK_STRAIN_SE): 1944705 tup, 1 comp, [0, 10.5]
Array 14 (FAILED): 1944705 tup, 1 comp, [0, 0]

ACTIVE SCALAR:
VTK_STRESS_VM (6): [0, 361.9]

bounds: 0.5740 24.3500 0.4920 27.4700 0.0000 8.5280
el_size_mm: 0.0820 0.0820 0.0820
origin: 0.5740 0.4920 0.0000
dim: 290 329 104
scalar: 0.0000 361.9000

AIM File
!> Image Data starts at byte offset 160
!> Image Data starts at byte offset 8921
!-----
Volume CANNON_RL_FEM.AIM
AIM Version 1.6
!
dim 301 340 104

```

```

xterm
AIM File -----
!> Image Data starts at byte offset 160
!> Image Data starts at byte offset 8921
!-----
Volume                CANNON_RL_FEM.AIM
AIM Version            1.6
!
dim                    301    340    104
off                    0      0      0
pos                    654    448    3
element size in mm     0.0820 0.0820 0.0820
physical size in mm    24.6820 27.8800 8.5280
!
Size of data in bytes  1
!-----
!> Image Data starts at byte offset 160
!> Image Data starts at byte offset 8921
!> Reading memory blocks...
!> Reading memory blocks done!
!> Restoring D3AnyImage020...
!> Restoring done!
!> Uncompressing Format: D1TbinCmp ...
!> Uncompressing done.

Data checking -----
Number of elements match.
Memory allocated (kb): 41576

Setting data -----
Copying array VTK_STRESS_VM

Creating log -----
Procedure:                FE output

AIM file                  CANNON_RL_FEM.AIM
DAT file                  CANNON_RL_FEM_z.dat
Scalar name               VTK_STRESS_VM
Scalar range min          0.0000
Scalar range max          361.9000

!-----

!> Writing AimVersion020 requested...
!> Writing current AIM Version 030 as IEEE floats.
!> Converting Image from VAX float to IEEE float...
!> Start Writing MemBlock 64 bit...
!> AimVersion030 written.
!> After writing on disk, converting Image in memory back to VAX float...
!> Writing done!
!> Writing done!
!-----
Volume                CANNON_RL_FEM_z_svm.aim
AIM Version            2.4
!
dim                    301    340    104
off                    0      0      0
pos                    654    448    3
element size in mm     0.0820 0.0820 0.0820
physical size in mm    24.6820 27.8800 8.5280
!
Size of data in bytes  4
!-----

Writing data -----
File written: CANNON_RL_FEM_z_svm.aim
bash-3.2$

```

- Float data!

```

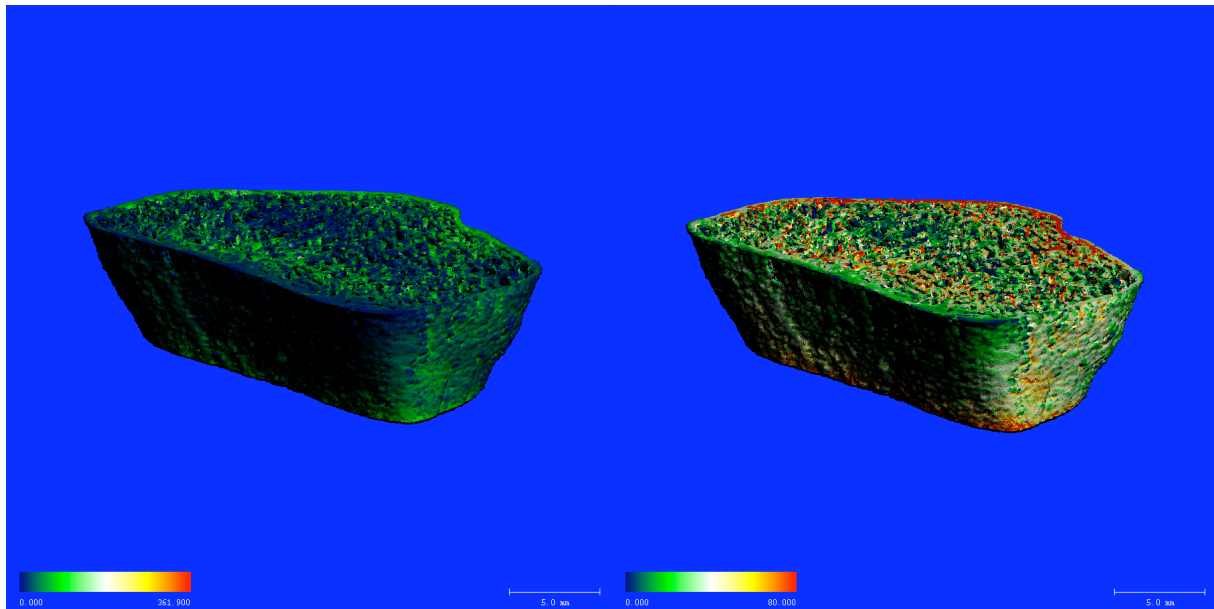
xterm
bash-3.2$ aix CANNON_RL_FEM_z_svm.aim
!> Image Data starts at byte offset 280
!> Image Data starts at byte offset 2359
!-----
Volume                CANNON_RL_FEM_z_svm.aim
AIM Version            2.4
!
dim                    301    340    104
off                    0      0      0
pos                    654    448    3
element size in mm     0.0820 0.0820 0.0820
physical size in mm    24.6820 27.8800 8.5280
!
Size of data in bytes  4
!-----
bash-3.2$

```

Visualize with uct_3d

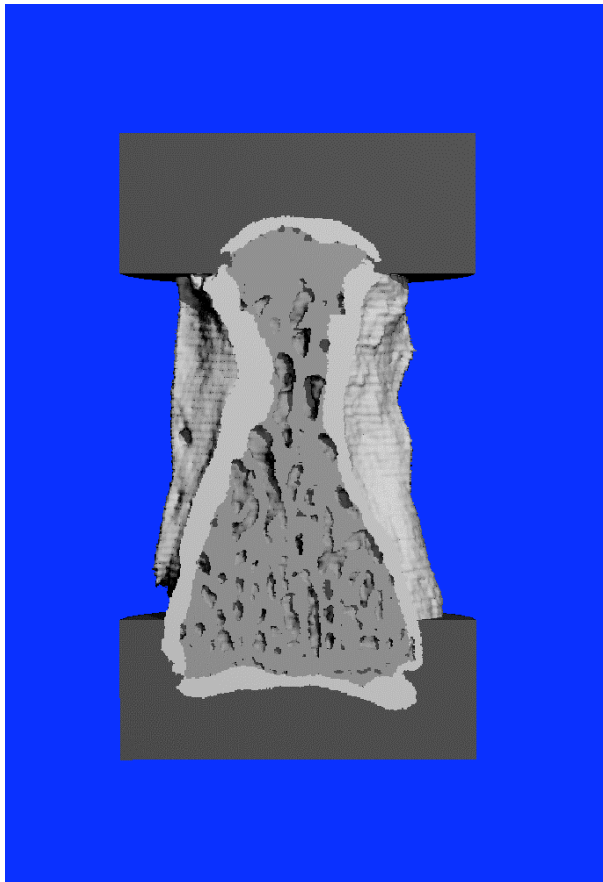
- Transfer back to VMS station
- Adjust the scale with Options:Values

- Now one can access all the standard IPL commands to do further evaluation with this data set.



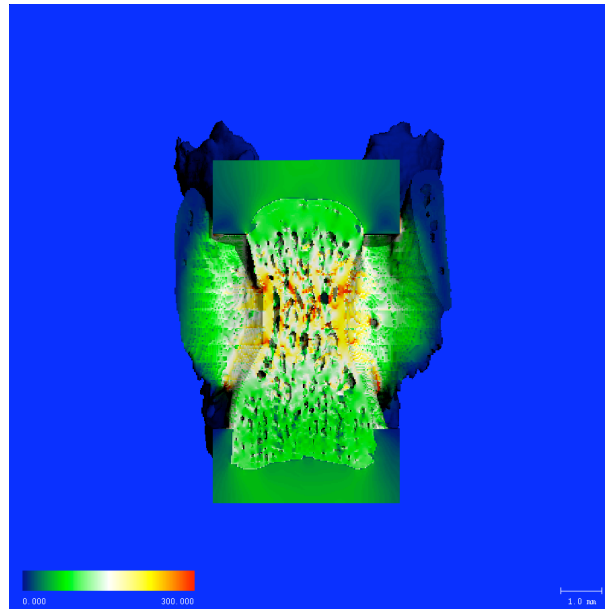
End Caps

Modeling with Endcaps



AppDirectMechanicsGenerator requires the following options if we are interested in a mid-plane analysis of the load sharing, and if we want to ensure the BCs are applied to the platens (and not the min/max Z values):

- `-f #` : Apply BCs to a specific material id only (df. all)
- `-p` : Generate an element set for the plane midway along testing axis
- Specifying `-f 56` forces the BCs to be applied on material 56 only (i.e., the end caps). This is useful when the bone extends beyond the endcaps.



- Running the FE model, include the parameter “-exclude 56” if the end caps are identified as 56. This removes them from the post-processing analysis of stress distribution, etc.

```

xterm
bash-3.2$ faim_d

Mesh-free preconditioned conjugate gradient iterative FE solver

Usage: faim ifile [-h]

ifile          : Input file (without extension '.inp').
-solver name   : Set the solver. Currently st and mt are supported.
-threads #    : Set the number of threads (0=automatic).
-device #     : Set the device for the nv solver.
-limit #      : Set maximum number of iterations.
-h            : Help information.
-s            : Suppress echo of node/connectivity output.
-nd           : Suppress nodal displacement output.
-ss           : Suppress element stress output.
-sn           : Suppress element strain output.
-rf           : Suppress nodal reaction force output.
-nodat        : Suppress writing dat file.
-allsteps     : Write hdr and dat file for each load step.
-loadshare    : Load sharing by node sets (df, element sets).
-exclude #    : Exclude a material from the analysis (e.g., endcaps).

Version 4.03 - Copyright (c) Steven K Boyd, skboyd@ucalgary.ca

bash-3.2$

```

Results file

```

=====
Time stamp:          29/09/2009          14:41:55
=====

Table 1: Model Input
-----
FAIM version:                4.01
Filename:                    AMMANN_VERT_01_ENDCAPS_R02_z
Element:                      hexahedron
Element dim X:                0.0320
Element dim Y:                0.0320
Element dim Z:                0.0330
Number of nodes:              3138944
Number of elements:           2891074
Number of integration points: 8

```

```

Number of freedoms per node:      3
Number of nodes per element:     8
Dimension of problem:            3
Tolerance:                      0.1000E-03
Maximum number of iterations:    30000
Number of equations:             9397101
Number of steps:                 1
Number of steps at exit:         1
Maximum compression:             -0.4930E-01
Maximum tension:                 0.2950E-01
Total load:                      0.0000E+00
=====

```

Table 2: Model Material Table

```

-----
Number of materials available:    254
Number of materials used:        3
Isotropic material:              true
-----

```

id	E	v	G
127	0.1934E+05	0.3000E+00	0.7438E+04
125	0.1934E+05	0.3000E+00	0.7438E+04
56	0.3000E+04	0.3000E+00	0.1154E+04

Table 3: Model Material Distribution

material	# voxels	%
127	357630	12.3701
125	599806	20.7468
56	1933638	66.8830
total	2891074	100.0000

Table 4: Conjugate Gradient Load Step

```

-----
Current step:                    1
Number of steps:                 1
Load step at exit:              1
Failed voxels:                  0
Convergence criteria:            0.1000E-03
Convergence measure:            0.9451E-04
Iterations to convergence:       1532
=====

```

Table 5: Tissue Stresses

```

-----
Material:                        ALL
Number of elements:              2891074
-----

```

	s11	s22	s33	s12	s23	s31	sVM
average	-0.1610E-01	0.5799E-02	-0.5123E+02	-0.1237E-02	0.2687E-01	0.4980E-01	0.5669E+02
std_dev	0.1035E+02	0.1079E+02	0.5787E+02	0.4608E+01	0.1173E+02	0.1094E+02	0.5724E+02
minimum	-0.2911E+03	-0.2237E+03	-0.9088E+03	-0.8763E+02	-0.1769E+03	-0.2027E+03	0.4357E-01
maximum	0.2038E+03	0.2041E+03	0.4216E+02	0.1119E+03	0.1929E+03	0.2382E+03	0.7154E+03
skewness	-0.9526E+00	-0.6800E+00	-0.1983E+01	-0.2234E+00	0.2026E+00	-0.1837E+00	0.1812E+01
kurtosis	0.1281E+02	0.1043E+02	0.4448E+01	0.1478E+02	0.1125E+02	0.1214E+02	0.3509E+01
median	0.9328E+00	0.7357E+00	-0.3285E+02	0.6570E-01	0.9737E-03	-0.5067E-01	0.3779E+02
percentile05	-0.1833E+02	-0.1808E+02	-0.1831E+03	-0.6366E+01	-0.1774E+02	-0.1558E+02	0.4330E+01
percentile25	-0.1760E+01	-0.2091E+01	-0.6612E+02	-0.1606E+01	-0.1654E+01	-0.2417E+01	0.1735E+02
percentile75	0.3848E+01	0.3356E+01	-0.1177E+02	0.1686E+01	0.1621E+01	0.2445E+01	0.7650E+02
percentile95	0.1230E+02	0.1569E+02	-0.6126E+00	0.6225E+01	0.1809E+02	0.1641E+02	0.1863E+03
fraction_below_zero	0.3949E+00	0.4056E+00	0.9771E+00	0.4860E+00	0.4995E+00	0.5175E+00	0.0000E+00
ave_neg	-0.7707E+01	-0.7543E+01	-0.5245E+02	-0.2845E+01	-0.5913E+01	-0.5682E+01	0.0000E+00
med_neg	-0.3463E+01	-0.3563E+01	-0.3421E+02	-0.1677E+01	-0.1659E+01	-0.2248E+01	0.0000E+00
ave_pos	0.5003E+01	0.5157E+01	0.7738E+00	0.2688E+01	0.5954E+01	0.6199E+01	0.5669E+02
med_pos	0.3103E+01	0.2778E+01	0.4277E+00	0.1618E+01	0.1617E+01	0.2633E+01	0.3779E+02

```

-----
Material:                        ALL EXCEPT 56
Number of elements:              957436
-----

```

	s11	s22	s33	s12	s23	s31	sVM
average	-0.2838E+01	-0.1568E+01	-0.1116E+03	-0.1056E-01	-0.7634E-01	0.6466E+00	0.1199E+03
std_dev	0.1666E+02	0.1793E+02	0.6394E+02	0.7469E+01	0.1985E+02	0.1813E+02	0.5832E+02
minimum	-0.2911E+03	-0.2237E+03	-0.9088E+03	-0.8763E+02	-0.1769E+03	-0.2027E+03	0.1761E+01
maximum	0.2038E+03	0.2041E+03	0.4216E+02	0.1119E+03	0.1929E+03	0.2382E+03	0.7154E+03

```

skewness -0.1066E+00 -0.1411E+00 -0.1148E+01 -0.1556E+00 0.1384E+00 -0.2076E+00 0.1182E+01
kurtosis 0.3559E+01 0.2072E+01 0.1358E+01 0.4711E+01 0.2217E+01 0.3040E+01 0.1262E+01
median -0.2565E+01 -0.1634E+01 -0.9259E+02 0.1631E+00 -0.5328E+00 0.1241E+01 0.1009E+03
percentile05 -0.2980E+02 -0.3116E+02 -0.2395E+03 -0.1201E+02 -0.3196E+02 -0.2956E+02 0.5608E+02
percentile25 -0.1189E+02 -0.1123E+02 -0.1455E+03 -0.3629E+01 -0.1062E+02 -0.8237E+01 0.7686E+02
percentile75 0.6283E+01 0.8226E+01 -0.6541E+02 0.3717E+01 0.9999E+01 0.9666E+01 0.1511E+03
percentile95 0.2342E+02 0.2825E+02 -0.3905E+02 0.1152E+02 0.3331E+02 0.2976E+02 0.2373E+03
fraction_below_zero 0.5826E+00 0.5522E+00 0.9983E+00 0.4874E+00 0.5170E+00 0.4585E+00 0.0000E+00
ave_neg -0.1308E+02 -0.1349E+02 -0.1118E+03 -0.5397E+01 -0.1394E+02 -0.1340E+02 0.0000E+00
med_neg -0.1004E+02 -0.9947E+01 -0.9271E+02 -0.3759E+01 -0.1014E+02 -0.9325E+01 0.0000E+00
ave_pos 0.1146E+02 0.1313E+02 0.5523E+01 0.5111E+01 0.1477E+02 0.1254E+02 0.1199E+03
med_pos 0.8482E+01 0.9831E+01 0.3596E+01 0.3599E+01 0.1055E+02 0.8713E+01 0.1009E+03

```

```

-----
Material: 127
Number of elements: 357630

```

```

.....
s11 s22 s33 s12 s23 s31 sVM
average -0.8081E+00 -0.1066E+01 -0.1256E+03 -0.7591E-02 -0.3067E+00 0.7331E+00 0.1348E+03
std_dev 0.1808E+02 0.2029E+02 0.7196E+02 0.7009E+01 0.2068E+02 0.1895E+02 0.6359E+02
minimum -0.2911E+03 -0.2237E+03 -0.9088E+03 -0.8763E+02 -0.1769E+03 -0.1747E+03 0.1899E+01
maximum 0.1241E+03 0.1856E+03 0.2476E+02 0.7400E+02 0.1929E+03 0.2382E+03 0.7154E+03
skewness -0.4378E+00 -0.4558E-01 -0.8541E+00 -0.2755E+00 0.1515E+00 -0.3819E+00 0.9055E+00
kurtosis 0.2992E+01 0.1178E+01 0.1723E+00 0.3873E+01 0.1775E+01 0.2607E+01 0.2250E+00
median -0.7314E+00 -0.2454E+01 -0.1028E+03 0.1097E+00 -0.8415E+00 0.1056E+01 0.1112E+03

```

```

-----
Material: 125
Number of elements: 599806

```

```

.....
s11 s22 s33 s12 s23 s31 sVM
average -0.4048E+01 -0.1868E+01 -0.1032E+03 -0.1232E-01 0.6101E-01 0.5951E+00 0.1110E+03
std_dev 0.1563E+02 0.1636E+02 0.5702E+02 0.7730E+01 0.1935E+02 0.1762E+02 0.5298E+02
minimum -0.1693E+03 -0.1808E+03 -0.7043E+03 -0.7925E+02 -0.1657E+03 -0.2027E+03 0.1761E+01
maximum 0.2038E+03 0.2041E+03 0.4216E+02 0.1119E+03 0.1662E+03 0.1724E+03 0.6378E+03
skewness 0.1184E+00 -0.2744E+00 -0.1295E+01 -0.1015E+00 0.1316E+00 -0.7900E-01 0.1352E+01
kurtosis 0.4252E+01 0.2775E+01 0.2477E+01 0.4957E+01 0.2523E+01 0.3334E+01 0.2273E+01
median -0.3625E+01 -0.1211E+01 -0.8777E+02 0.1970E+00 -0.3234E+00 0.1344E+01 0.9536E+02

```

```

-----
Material: 56
Number of elements: 1933638

```

```

.....
s11 s22 s33 s12 s23 s31 sVM
average 0.1381E+01 0.7853E+00 -0.2134E+02 0.3378E-02 0.7797E-01 -0.2457E+00 0.2538E+02
std_dev 0.4114E+01 0.3591E+01 0.1694E+02 0.2033E+01 0.3235E+01 0.4014E+01 0.1595E+02
minimum -0.1192E+03 -0.1213E+03 -0.9747E+02 -0.2698E+02 -0.6562E+02 -0.6260E+02 0.4357E-01
maximum 0.2532E+02 0.2157E+02 0.3841E+01 0.3347E+02 0.5524E+02 0.5889E+02 0.1297E+03
skewness -0.3387E+01 -0.3235E+01 -0.6135E+00 0.1528E-01 0.3293E+00 -0.3852E+00 0.4471E+00
kurtosis 0.4273E+02 0.4302E+02 -0.5661E+00 0.3228E+01 0.1525E+02 0.8079E+01 -0.6165E+00
median 0.1343E+01 0.9706E+00 -0.1757E+02 0.5253E-01 0.1203E-01 -0.9866E-01 0.2310E+02

```

=====

Table 6: Tissue Strains

```

-----
Material: ALL
Number of elements: 2891074

```

```

.....
e11 e22 e33 e12 e23 e31 SED
average 0.2215E-02 0.2071E-02 -0.6791E-02 0.1488E-05 0.4180E-04 -0.1136E-03 0.2528E+00
std_dev 0.2082E-02 0.1448E-02 0.4995E-02 0.1553E-02 0.2760E-02 0.3175E-02 0.3533E+00
minimum -0.2986E-01 -0.3054E-01 -0.3912E-01 -0.2338E-01 -0.5687E-01 -0.5425E-01 0.2965E-06
maximum 0.1074E-01 0.1157E-01 0.9334E-02 0.2901E-01 0.4787E-01 0.5103E-01 0.1665E+02
skewness 0.1541E+00 -0.1874E+00 -0.7892E+00 0.2616E-02 0.2741E+00 -0.4083E+00 0.3870E+01
kurtosis 0.2427E+01 0.6178E+01 -0.1092E-01 0.4358E+01 0.1152E+02 0.8417E+01 0.3120E+02
median 0.1764E-02 0.1927E-02 -0.5459E-02 0.3443E-04 0.7594E-06 -0.3739E-04 0.1432E+00
percentile05 -0.3814E-03 -0.4275E-04 -0.1592E-01 -0.2664E-02 -0.4056E-02 -0.5058E-02 0.2946E-02
percentile25 0.7512E-03 0.1152E-02 -0.1000E-01 -0.7958E-03 -0.8868E-03 -0.1247E-02 0.4435E-01
percentile75 0.3623E-02 0.2986E-02 -0.3152E-02 0.7937E-03 0.9212E-03 0.1123E-02 0.3121E+00
percentile95 0.5891E-02 0.4583E-02 -0.2694E-03 0.2584E-02 0.4269E-02 0.4579E-02 0.9270E+00
fraction_below_zero 0.1053E+00 0.5499E-01 0.9743E+00 0.4860E+00 0.4995E+00 0.5175E+00 0.0000E+00
ave_neg -0.7322E-03 -0.6953E-03 -0.6984E-02 -0.1153E-02 -0.1625E-02 -0.2047E-02 0.0000E+00
med_neg -0.3562E-03 -0.3329E-03 -0.5623E-02 -0.8280E-03 -0.8885E-03 -0.1179E-02 0.0000E+00
ave_pos 0.2563E-02 0.2232E-02 0.5104E-03 0.1094E-02 0.1705E-02 0.1960E-02 0.2528E+00
med_pos 0.2047E-02 0.2023E-02 0.2074E-03 0.7631E-03 0.9194E-03 0.1192E-02 0.1432E+00

```

```

-----
Material: ALL EXCEPT 56
Number of elements: 957436

```

```

.....
s11 s22 s33 s12 s23 s31 sVM
average 0.1608E-02 0.1694E-02 -0.5701E-02 -0.1419E-05 -0.1026E-04 0.8693E-04 0.4693E+00
std_dev 0.1073E-02 0.9202E-03 0.3081E-02 0.1004E-02 0.2669E-02 0.2437E-02 0.5042E+00
minimum -0.7179E-02 -0.8654E-02 -0.3912E-01 -0.1178E-01 -0.2378E-01 -0.2724E-01 0.8199E-04

```

```

maximum 0.9805E-02 0.1157E-01 0.2358E-02 0.1504E-01 0.2593E-01 0.3203E-01 0.1665E+02
skewness 0.7645E+00 0.7373E+00 -0.1213E+01 -0.1556E+00 0.1384E+00 -0.2076E+00 0.2692E+01
kurtosis 0.1199E+01 0.2542E+01 0.1421E+01 0.4711E+01 0.2217E+01 0.3040E+01 0.1599E+02
median 0.1413E-02 0.1568E-02 -0.4705E-02 0.2193E-04 -0.7163E-04 0.1668E-03 0.2627E+00
percentile05 0.1577E-03 0.4402E-03 -0.1202E-01 -0.1615E-02 -0.4296E-02 -0.3973E-02 0.7789E-01
percentile25 0.9027E-03 0.1141E-02 -0.7249E-02 -0.4878E-03 -0.1428E-02 -0.1107E-02 0.1482E+00
percentile75 0.2162E-02 0.2128E-02 -0.3516E-02 0.4996E-03 0.1344E-02 0.1299E-02 0.6068E+00
percentile95 0.3656E-02 0.3434E-02 -0.2281E-02 0.1548E-02 0.4477E-02 0.4000E-02 0.1502E+01
fraction_below_zero 0.3526E-01 0.1997E-01 0.9994E+00 0.4874E+00 0.5170E+00 0.4585E+00 0.0000E+00
ave_neg -0.4049E-03 -0.5354E-03 -0.5705E-02 -0.7256E-03 -0.1874E-02 -0.1801E-02 0.0000E+00
med_neg -0.2739E-03 -0.3575E-03 -0.4707E-02 -0.5053E-03 -0.1363E-02 -0.1254E-02 0.0000E+00
ave_pos 0.1682E-02 0.1739E-02 0.3656E-03 0.6871E-03 0.1985E-02 0.1685E-02 0.4693E+00
med_pos 0.1451E-02 0.1586E-02 0.2538E-03 0.4838E-03 0.1419E-02 0.1171E-02 0.2627E+00

```

```

Material: 127
Number of elements: 357630

```

```

.....
s11 s22 s33 s12 s23 s31 SVM
average 0.1923E-02 0.1906E-02 -0.6466E-02 -0.1021E-05 -0.4123E-04 0.9855E-04 0.5863E+00
std_dev 0.1078E-02 0.9749E-03 0.3431E-02 0.9423E-03 0.2780E-02 0.2548E-02 0.5815E+00
minimum -0.7179E-02 -0.8654E-02 -0.3912E-01 -0.1178E-01 -0.2378E-01 -0.2348E-01 0.8368E-04
maximum 0.9805E-02 0.1044E-01 0.2090E-02 0.9948E-02 0.2593E-01 0.3203E-01 0.1665E+02
skewness 0.5052E+00 0.6635E+00 -0.9341E+00 -0.2755E+00 0.1515E+00 -0.3819E+00 0.2162E+01
kurtosis 0.7855E+00 0.1316E+01 0.2258E+00 0.3873E+01 0.1775E+01 0.2607E+01 0.1305E+02
median 0.1712E-02 0.1776E-02 -0.5183E-02 0.1475E-04 -0.1131E-03 0.1420E-03 0.3212E+00

```

```

Material: 125
Number of elements: 599806

```

```

.....
s11 s22 s33 s12 s23 s31 SVM
average 0.1421E-02 0.1567E-02 -0.5245E-02 -0.1657E-05 0.8202E-05 0.8000E-04 0.3995E+00
std_dev 0.1025E-02 0.8615E-03 0.2753E-02 0.1039E-02 0.2601E-02 0.2369E-02 0.4372E+00
minimum -0.6983E-02 -0.5415E-02 -0.3407E-01 -0.1065E-01 -0.2228E-01 -0.2724E-01 0.8199E-04
maximum 0.9595E-02 0.1157E-01 0.2358E-02 0.1504E-01 0.2234E-01 0.2318E-01 0.1164E+02
skewness 0.9802E+00 0.7318E+00 -0.1353E+01 -0.1015E+00 0.1316E+00 -0.7900E-01 0.3184E+01
kurtosis 0.1994E+01 0.3752E+01 0.2533E+01 0.4957E+01 0.2523E+01 0.3334E+01 0.1884E+02
median 0.1222E-02 0.1483E-02 -0.4461E-02 0.2649E-04 -0.4348E-04 0.1806E-03 0.2350E+00

```

```

Material: 56
Number of elements: 1933638

```

```

.....
s11 s22 s33 s12 s23 s31 SVM
average 0.2516E-02 0.2258E-02 -0.7331E-02 0.2927E-05 0.6757E-04 -0.2130E-03 0.1456E+00
std_dev 0.2374E-02 0.1616E-02 0.5633E-02 0.1762E-02 0.2804E-02 0.3479E-02 0.1613E+00
minimum -0.2986E-01 -0.3054E-01 -0.2522E-01 -0.2338E-01 -0.5687E-01 -0.5425E-01 0.2965E-06
maximum 0.1074E-01 0.1142E-01 0.9334E-02 0.2901E-01 0.4787E-01 0.5103E-01 0.3612E+01
skewness -0.1756E+00 -0.4987E+00 -0.5260E+00 0.1528E-01 0.3293E+00 -0.3852E+00 0.1678E+01
kurtosis 0.1697E+01 0.5725E+01 -0.6464E+00 0.3228E+01 0.1525E+02 0.8079E+01 0.5152E+01
median 0.2296E-02 0.2294E-02 -0.6257E-02 0.4552E-04 0.1043E-04 -0.8550E-04 0.8235E-01

```

Table 7: Nodal Displacements

```

Number of node sets: 3

```

```

Node set: 1
Number of nodes: 19731

```

```

+-----
Ux Uy Uz
average -0.7189E-02 0.3505E-02 -0.9091E-01
std_dev 0.5740E-02 0.4352E-02 0.7623E-08
minimum -0.1564E-01 -0.5545E-02 -0.9091E-01
maximum 0.2366E-02 0.1161E-01 -0.9091E-01
median -0.7772E-02 0.3562E-02 -0.9091E-01

```

```

Node set: 2
Number of nodes: 19731

```

```

+-----
Ux Uy Uz
average 0.4079E-02 -0.3221E-02 0.0000E+00
std_dev 0.6345E-02 0.5470E-02 0.0000E+00
minimum -0.4713E-02 -0.1266E-01 0.0000E+00
maximum 0.1468E-01 0.6217E-02 0.0000E+00
median 0.3228E-02 -0.2986E-02 0.0000E+00

```

```

Node set: 3
Number of nodes: 3834

```

```

+-----
Ux Uy Uz
average 0.4150E-02 -0.6676E-03 -0.5202E-01

```

```

std_dev 0.1925E-02 0.1346E-02 0.1574E-02
minimum -0.1063E-02 -0.4800E-02 -0.5626E-01
maximum 0.7702E-02 0.3096E-02 -0.4688E-01
median 0.4413E-02 -0.7132E-03 -0.5197E-01

```

```

=====
=====

```

Table 8: Nodal Forces

```

-----
Number of node sets: 3
-----
Node set: 1
Number of nodes: 19731
+-----
          Fx          Fy          Fz
total 0.4984E-02 0.1008E-02 -0.5534E+03
average 0.2526E-06 0.5109E-07 -0.2805E-01
std_dev 0.1400E-04 0.1381E-04 0.1374E-01
minimum -0.7518E-04 -0.1109E-03 -0.4965E-01
maximum 0.1160E-03 0.1140E-03 0.7305E-04
median 0.1964E-06 -0.8082E-08 -0.2891E-01
-----

```

```

Node set: 2
Number of nodes: 19731
+-----
          Fx          Fy          Fz
total -0.7607E-02 -0.5229E-02 0.5533E+03
average -0.3855E-06 -0.2650E-06 0.2804E-01
std_dev 0.1762E-05 0.1900E-05 0.1797E-01
minimum -0.6550E-05 -0.6655E-05 -0.1498E-02
maximum 0.5472E-05 0.5216E-05 0.6979E-01
median -0.2353E-06 -0.2340E-06 0.2405E-01
-----

```

```

Node set: 3
Number of nodes: 3834
+-----
          Fx          Fy          Fz
total -0.4558E-02 0.1357E-02 0.6434E-02
average -0.1189E-05 0.3539E-06 0.1678E-05
std_dev 0.4783E-04 0.4867E-04 0.3803E-04
minimum -0.8291E-03 -0.9318E-03 -0.3767E-03
maximum 0.1324E-02 0.1424E-02 0.9377E-03
median -0.3577E-06 -0.2739E-06 0.1237E-05
-----

```

Table 9: Load Sharing (by elements)

```

-----
Number of element sets: 3
Element area xy face: 0.1024E-02
Element area yz face: 0.1056E-02
Element area zx face: 0.1056E-02
-----
Element set: 1
Number of elements: 19415
+-----
material      Fx          Fy          Fz          % Fz
56 0.6471E+02 0.3055E+02 -0.5534E+03 100.00
-----
total 0.6471E+02 0.3055E+02 -0.5534E+03 100.00
-----

```

```

Element set: 2
Number of elements: 19415
+-----
material      Fx          Fy          Fz          % Fz
56 0.8599E+02 0.6456E+02 -0.5533E+03 100.00
-----
total 0.8599E+02 0.6456E+02 -0.5533E+03 100.00
-----

```

```

Element set: 3
Number of elements: 3063
+-----
material      Fx          Fy          Fz          % Fz
127 -0.9460E+01 -0.1501E+02 -0.2732E+03 49.38
125 -0.6836E+01 -0.2011E+02 -0.2801E+03 50.62
-----
total -0.1630E+02 -0.3512E+02 -0.5533E+03 100.00
-----

```

NOTE: Total Fx & Fy are determined by summing over the element faces. Therefore, total Fx & Fy are different than reported in Nodal Forces (Table 8). Total Fz

should be identical.

=====

Table 10: Failure Load Estimate

Pistola Criterion for Energy-Equivalent-Strain (EES)
(*) Results valid for linear, isotropic model only.

```
-----
Number of elements in analysis:          957436
Excluded material id:                   56
.....
Critical volume (%):                    2.0000
Critical EES:                           0.0070
EES at vol_crit:                        0.0141
Factor (from table):                    0.4975E+00
Reaction force Z:                        -0.5534E+03
Failure load (rfz / factor) [N]:        -0.2753E+03
Stiffness [N/mm]:                       0.6088E+04
-----
```

Distribution of energy-equivalent-strain: EES = sqrt(2U/E).

```
.....
                        EES
average 0.6231E-02
std_dev 0.3115E-02
minimum 0.9208E-04
maximum 0.4149E-01
skewness 0.1191E+01
kurtosis 0.1348E+01
median 0.5212E-02
-----
```

Distribution of failed materials.

```
.....
material  # els  %
-----
127       10977  57.3241
125       8172  42.6759
-----
total     19149  100.0000
-----
```

Factor table:

	crit_vol	crit_ees				
%	# vox	0.0050	0.0060	0.0070	0.0080	0.0090
1.00	957436	0.3280E+00	0.3937E+00	0.4593E+00	0.5249E+00	0.5905E+00
2.00	1914872	0.3553E+00	0.4264E+00	0.4975E+00	0.5686E+00	0.6396E+00
3.00	2872308	0.3738E+00	0.4485E+00	0.5233E+00	0.5980E+00	0.6728E+00
4.00	3829744	0.3886E+00	0.4663E+00	0.5440E+00	0.6218E+00	0.6995E+00
5.00	4787180	0.4012E+00	0.4815E+00	0.5617E+00	0.6420E+00	0.7222E+00
6.00	5744616	0.4126E+00	0.4951E+00	0.5776E+00	0.6601E+00	0.7426E+00
7.00	6702052	0.4233E+00	0.5079E+00	0.5926E+00	0.6773E+00	0.7619E+00

Table 20: Computational Cost

```
-----
Number of threads:                        8
Device number:                           0
Solver:                                  multi-threaded
Precision:                                double
-----
```

Computation time	wall (s)		cpu (s)	
	time	delta	time	delta
Read input	29.2410	29.2410	28.2085	28.2085
Pre-processing	66.8430	37.6020	62.1202	33.9117
Solver	715.9410	649.0980	4691.9499	4629.8297
Write DAT file	809.2990	93.3580	4783.3397	91.3898
Element summary	852.1680	42.8690	4826.2061	42.8664
Nodal summary	853.3110	1.1430	4827.3494	1.1433
Load sharing	853.3190	0.0080	4827.3567	0.0072
Failure estimate	854.0030	0.6840	4828.0414	0.6847
% solver	83.8	%	97.2	%
% pre/post	16.2	%	2.8	%
Charged time	854.0030	s	4828.0414	s

Table 19: One Liner

```

=====
yy      faim_version      num_els      num_nodes      tolerance      num_eqns      max_comp
max_tens num_materials      mat_id1      num_mat_id1      mat_id2      num_mat_id2      mat_id3
num_mat_id3      es1_fz_total      es1_fz_mat1      es1_fz_mat2      es1_fz_mat3      es2_fz_total      es2_fz_mat1
es2_fz_mat2      es2_fz_mat3      es3_fz_total      es3_fz_mat1      es3_fz_mat2      es3_fz_mat3      fz_total
failure_load      stiffness      wtime_solver      wtime_prepost      wtime_total
xy      4.01      2891074      3138944      0.1000E-03      9397101      -0.4930E-01
0.2950E-01      3      127      357630      125      599806      56
1933638      -0.5534E+03      -0.5534E+03      0.0000E+00      0.0000E+00      -0.5533E+03      -0.5533E+03
0.0000E+00      0.0000E+00      -0.5533E+03      -0.2732E+03      -0.2801E+03      0.0000E+00      -0.5534E+03
-0.2753E+03      0.6088E+04      649.10      204.90      854.00
=====

=====
Time stamp:      29/09/2009      14:56:09
=====

```